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Hood Canal Bridge

# MAPPING OF SUBTIDAL AND INTERTIDAL HABITAT RESOURCES: HOOD CANAL FLOATING BRIDGE, WASHINGTON

by


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16. ABSTRACT


The Washington State Department of Transportation is planning to repair and replace portions of the Hood Canal Bridge. To minimize construction impacts, it is important to spatially evaluate the location of biological resources, such as eelgrass (*Zostera marina*), geoduck clams (*Panopea abrupta*), and rockfish (*Sebastes* spp.), near the bridge, particularly at the eastern and western termini, and associated construction sites.

An underwater mapping effort was conducted during January 2001, during a season noted for dieback of eelgrass and senescence, whereas CASI imagery was collected during the summer of 2000 when eelgrass cover was at a maximum. Although the two methods produced some minor differences in the eelgrass patch margins, the vast majority of the areas overlapped along the eastern terminus where both methods were employed. Hence, the resulting maps for both the eastern and western termini should be considered accurate delineations of eelgrass (cover type and geopositional accuracy). At both the eastern and western termini, close to the bridge, a general lack of eelgrass continuity was noted. However, continuous beds were mapped on both sides at varying distances from the bridge.

The merged intertidal-subtidal eelgrass maps are the result of one of the first integrated mapping efforts of nearshore eelgrass in the Northwest. The spatially referenced data collected on substrate type, fish, and macroinvertebrates will allow examination of habitat usage in the future near the eastern and western termini of the bridge.


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# Mapping of Subtidal and Intertidal Habitat Resources: Hood Canal Floating Bridge, Washington


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# Introduction

The Washington State Department of Transportation (WSDOT) is planning to repair and replace portions of the Hood Canal Bridge (HCB) in the near future. Construction activities include replacement of the eastern half of the floating structure, placement of 20 new anchors with associated benching and filling, foundation drilling, addition of concrete footings and girders, bridge widening, demolition of existing structures, and anchored barges. Construction activities will occur over nearshore habitats on both the eastern and western approaches to the bridge (Figure 1). The potential impacts on marine resources include shading from barges, noise and vibration from heavy equipment use, and bottom disturbance from anchors and material placement. To minimize these impacts, it is important to spatially evaluate the location of biological resources, such as eelgrass (*Zostera marina*), geoduck clams (*Panopea abrupta*), and rockfish (*Sebastes* spp.) in the vicinity of the bridge and associated construction sites.

This assessment was a collaborative effort between the Wetland Ecosystem Team at the University of Washington, Earth Design Consultants, Inc. (EDC), Marine Resources Consultants, Inc. (MRC), and the Battelle Marine Sciences Laboratory (MSL). The intertidal eelgrass habitat was evaluated and mapped using the Compact Airborne Spectrographic Imager (CASI). Flight-line data were collected in July 2000 as part of an ongoing evaluation of estuarine and nearshore habitat status of juvenile summer chum salmon in Hood Canal, Washington (Simenstad 2000). This evaluation included a high-resolution assessment of intertidal eelgrass habitat in the study area, coordinated by the Point-No-Point Treaty Council as part of an investigation of the cumulative impact of eelgrass habitat landscape modifications in Hood Canal and the eastern Strait of Juan de Fuca subestuaries and shorelines (Simenstad et. al., 1999). A separate report on the details of the CASI mapping effort as part of this project is included with this report (Appendix A).

The subtidal benthic resource assessment was conducted using underwater video by the MSL. Underwater video surveys were conducted in January 2001 by MRC, Inc. The area covered included the eastern and western terminus of the HCB, as well as the area of the planned placement of new anchor blocks on the eastern end of the bridge. Assessed resources included eelgrass habitat, substrate type, macroalgae, macroinvertebrates, and fish. The eelgrass data were merged with the CASI hyperspectral data (Appendix A) to create one layer of intertidal/subtidal coverage. Other benthic resource data were also represented in a spatially geo-referenced context. In addition to this report, all data were delivered to WSDOT in ArcView geographic information system (GIS) format for their use.

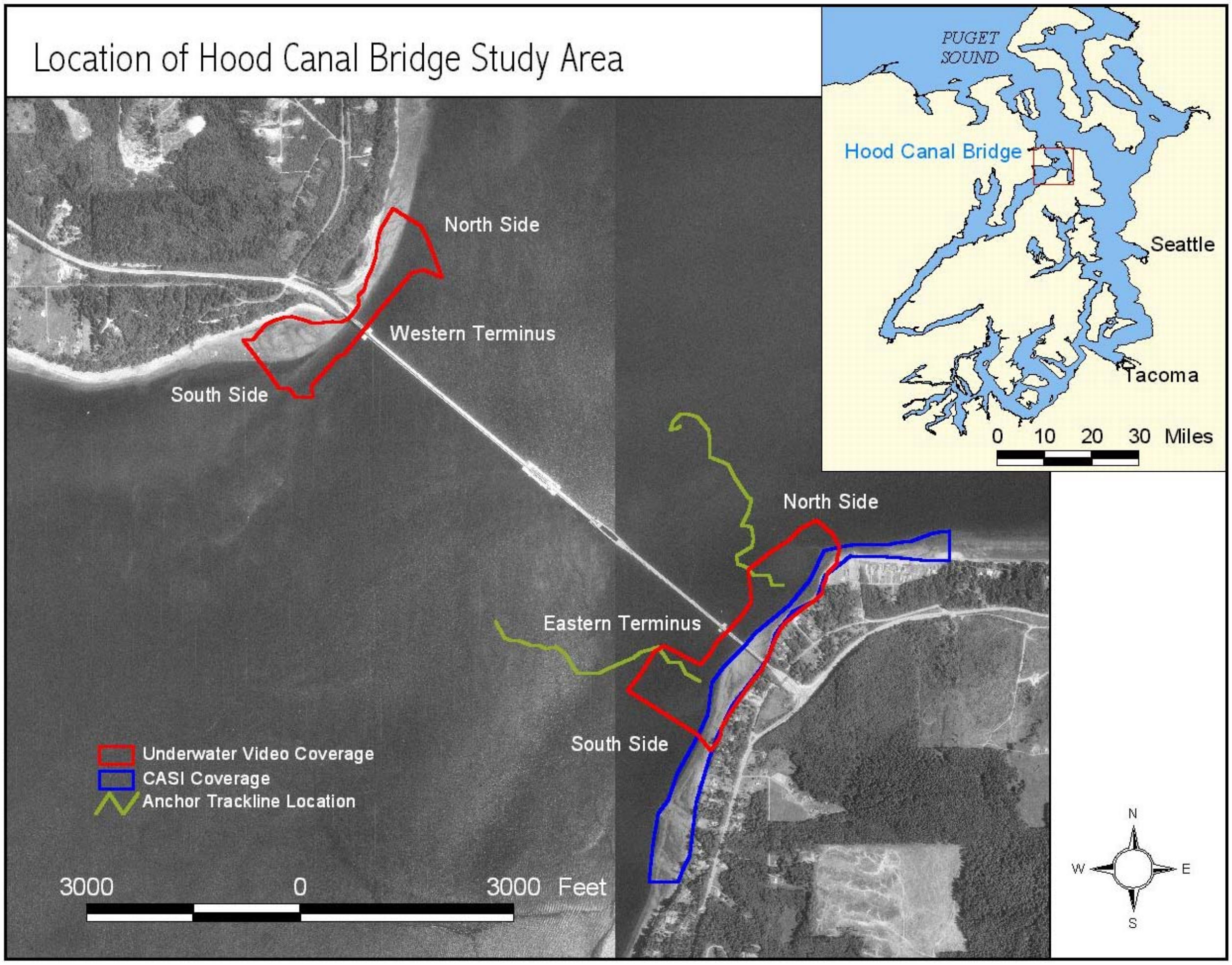


**Figure 1.** Location of the Hood Canal Bridge showing the extent of the underwater video survey and the CASI hyperspectral data.

# Methods

## *Underwater Video Data Collection*

Underwater video footage was collected in the nearshore subtidal environment at the eastern and western terminus of the HCB during January 2001. Coverage extended 500 m along the shoreline in either direction from the bridge structure (1 km per terminus) down to a depth of approximately –30 m mean lower low water (MLLW). A towed underwater video system was used by MRC, Inc., to collect the video footage of benthic habitat. A laptop computer equipped with a video overlay controller and data logger software was used to integrate differential global positioning system (dGPS) data (date, time, longitude, latitude), user-supplied transect information, and the video signal. The dGPS data were updated every 1 s, and transect information was recorded and stored directly onto VHS videotapes. Date, time, position, and transect information was also stored on the computer at 1-s intervals. Video footage was collected on tracklines perpendicular to shore, approximately 25 m apart, from the shoreline out to –30 m depth (approximately 40 transects at each terminus of the bridge). Three transects were also collected parallel and close to shore to encompass areas that would likely contain eelgrass habitat. Additional “meander” transects were surveyed close to the bridge structure to provide added detail in the areas of primary concern. Transects were also surveyed near the vicinity of the planned placement of new anchor blocks down to a depth of approximately 120 m.

### *Video Analysis*

Five primary habitat/species categories were analyzed on the videotapes: eelgrass, substrate, fish, macroinvertebrates, and senescent/decaying vegetation. For each habitat or substrate type, a coded classification scheme was used to identify the video observation in a spreadsheet format that was later converted to a GIS format. The general categories, represented as columns in the spreadsheet, are shown in Table 1.

***Eelgrass***—Eelgrass (*Z. marina*) habitat was assessed and classified using a modification of a semi-quantitative system used in Chesapeake Bay (Orth et al., 1998) to monitor seagrass coverage annually. This method estimates eelgrass density (percentage of cover) by visually comparing the bed with an enlarged Crown Density Scale similar to those developed for estimating crown cover of trees from aerial photography (Paine 1981).

**Table 1**. Classification Categories Used for Underwater Video Post-processing

| Category | # of Codes | Type of Code |
|---|---|---|
| Eelgrass | 5 | Density (% cover) |
| Senescent/Decaying Vegetation | 2 | Presence/absence |
| Dominant Substrate | 5 | >50% dominant surface cover |
| Other Material | 10 | Non-substrate surface cover (e.g., wood debris) |
| Fish Presence | 2 | Presence/absence |
| Fish Species ID | 22 | Identification |
| Individual/School | 2 | Behavior type |
| Fish density | 4 | Density |
| Number of fish | 0 to >100 | Total individuals |
| Invertebrate Species ID | 12 | Identification |
| Individual/Aggregate | 2 | Behavior type |
| Invertebrate Density | 4 | Density |
| Number of Invertebrates | 0 to >100 | Total individuals |

Modifying this method, five categories were used to classify eelgrass habitat on videotape:

- No eelgrass
- Very sparse—up to 10% coverage
- Moderate—10% to 50% coverage
- Dense— >50% coverage
- Edge of dense bed

***Substrate—***Substrate classifications were adapted from *Marine and Estuarine Habitat Classification System for Washington State* (Dethier 1990). They included:

- Sand—sand and mixed fines, 0.6 mm to 4 mm
- Gravel—small rocks or pebbles, 4 mm to 64 mm diameter
- Mixed Coarse—consisting of cobbles, gravel, shell and sand (none exceeding >70% surface cover)
- Cobble—rocks <256 mm (10") but >64 mm (2.5") diameter
- Boulder—rocks >256 mm

***Fish***—Fish were identified to the nearest species, genus, or class possible. Because fish were assessed using a relatively non-invasive, *in-situ* technique (underwater video), they were easily grouped into two categories related to their behavior: schooling and non-schooling. Five classifications or behaviors were recorded for fish: fish presence, behavior type (individual or schooling); species identification; fish density (<10 individuals; 10 to 100 individuals; >100); and the number of fish, if there were less than 10 and could be counted individually.

***Macroinvertebrates***—Macroinvertebrates were identified to the nearest species, genus or class possible. Five classifications were recorded for macroinvertebrates: presence or absence, species identification, behavior type (individual or aggregate), density (<5 individuals; 5 to 10 individuals; >10 individuals); and the number of macroinvertebrates, either counted or estimated.

## CASI Hyperspectral Imagery Collection and Analysis

The following is a brief summary of the full report on the CASI imagery acquisition and analysis provided in Appendix A. A CASI sensor collected digital radiometric information from two flight lines along the eastern shoreline of northern Hood Canal on July 2, 2000. A ground survey was conducted to associate reflectance spectra of intertidal habitat types with the CASI imagery at eight precisely located training sites between June 29 and July 2, 2000. A hand-held radiometer was used to record reflectance spectra from monotypic habitat strata (vegetation, substrate) at the same time of airborne image acquisition. A spectral library, used to select CASI band combinations for supervised classification, was constructed from these data.

CASI data were radiometrically corrected and supplied in ERDAS LAN format. Reflectance values were calculated using irradiance recorded by the incident light sensor, and original radiance values recorded by the CASI, resulting in a processed data file in which variation as a result of downwelling irradiance was removed. These data were geocorrected using filtered attitude data. CASI imagery was classified (see below) and imported into ESRI ArcView software for incorporation into a GIS dataset.

A series of ground control points (GCP) were established for this study. ERDAS Imagine was used to geometrically correct the CASI imagery by fitting the imagery to the control points using a 1st order polynomial model. Using this approach, root mean square error (RMSE) was measured as the spatial error associated with the GCPs following geometric correction.

A combination of unsupervised-supervised classification was used. Initially, an unsupervised classification using ERDAS Imagine software was performed, which resulted in 100 spectral categories that were subjected to a Maximum Likelihood classification. For supervised classification, spectral signatures from the training sites were extracted. Maximum Likelihood was used with the resulting signatures to group pixels that shared spectral characteristics. The eelgrass habitat landscape was delineated in raster form for eight aggregated cover classes: 1) dense eelgrass, 2) sparse eelgrass, 3) green algae, 4) sparse green algae, 5) brown algae, 6) sand, 7) gravel/cobble, and 8) oysters/gravel.

The accuracy of the supervised classification was tested in the field May 22 through May 23, 2001. To further evaluate the spatial accuracy of the CASI hyperspectral delineation of eelgrass in the lower tidal elevations, the hyperspectral data were compared with the subtidal-lower intertidal eelgrass map generated by MSL using underwater videography in January 2001. The MSL data were converted to a 1.5-meter pixel file that matched the CASI data, extracting all non-zero cells.

## *GIS Delineation of Habitat Types*

The underwater video data and the CASI imagery were imported into GIS software (ESRI ArcView), where the datasets were partitioned into georeferenced layers and eelgrass cover polygons were delineated. Both datasets were analyzed at the eastern terminus of the HCB. At the western terminus, however, CASI data were not available for analysis, and only underwater video data was used in the delineation. The four eelgrass-cover classes defined for delineation were 1) dense, 2) moderate, 3) sparse, and 4) patchy. These categories correspond to the classifications of the underwater video data, with the exception of the patchy class, which was created for small patches of moderate eelgrass cover in areas of bare sand or sparse eelgrass cover. Polygons were first delineated using the underwater video data, then merged with the CASI data. The CASI image data was converted to a grid file, which was converted to an ArcView polygon file using Spatial Analyst.

Merging the CASI and underwater video polygon datasets required a set of decision rules to guide the final delineation. These rules were as follows:

1) Where possible, the shape of the polygons was defined by the CASI data, which contained more detailed coverage than the video data;
2) Where possible, the classification of the polygons was determined by the underwater video data, which were more precise (more cover classes defined); if CASI polygons fell

outside of video coverage, then a classification of moderate was designated (unless contiguous with a sparse or dense classification of the video data);

3) The outer edge of the polygons (deeper limit of eelgrass) was defined by the underwater video data, because the CASI imagery was limited to the intertidal area;
4) The minimum mapping unit was 4 meters; patches smaller than this were aggregated into larger cover polygons;
5) When a discrepancy occurred between the underwater video data and the CASI imagery, the difference was "split," with the eelgrass delineation drawn halfway between the eelgrass classification of the two datasets (this distance was never more than a few meters except for the deeper extent, where the video data were used exclusively).

# Results

The study area encompassed 1040 m of shoreline along the eastern terminus of the HCB and 1006 m along the western terminus (Figure 1). At the eastern terminus, approximately 9000 m of video trackline data were collected and analyzed, and 82,905 $m^2$ of CASI hyperspectral imagery data classified. At the western terminus, 9957 m of video trackline data were analyzed (Table 2). Along the eastern portion of the bridge in the area of the cable anchors, 707 m of video trackline data were collected.

## *Eelgrass Habitat*

Eelgrass is present in both study areas (eastern and western terminus) and extensive in some areas. The north side of the western terminus contains the least amount of eelgrass (7590 $m^2$) (Table 3). The underwater video camera assessment indicates that no observable eelgrass exists from the bridge north for approximately 175 m (Figure 2). In addition, no dense patches of

**Table 2.** Spatial Coverage of Video Tracks (length in m) and CASI imagery (area in $m^2$) at Hood Canal Bridge.

| Region | Shoreline Length (m) | Length of Video tracks (m) | CASI coverage ($m^2$) |
|---|---|---|---|
| Eastern Terminus | | | |
| North Side | 605 | 4,278 | 37,066 |
| South Side | 435 | 4,693 | 45,839 |
| Western Terminus | | | |
| North Side | 505 | 4,872 | NA |
| South Side | 501 | 5,085 | NA |
| Anchor Area | | | |
| North Side | NA | 381 | NA |
| South Side | NA | 326 | NA |

**Table 3.** Basal Area Coverage ($m^2$) of Eelgrass Habitat using Merged Delineations of Underwater Video (subtidal) and CASI (intertidal) Polygons at the Eastern Terminus and Video Data Only at the Western Terminus

| Region | Patchy | 0 – 10% Sparse | 10 – 50% Moderate | > 50% Dense | Total |
|---|---|---|---|---|---|
| Eastern Terminus | | | | | |
| North Side | 0 | 1,647 | 12,866 | 2,299 | 16,812 |
| South Side | 0 | 5,619 | 17,759 | 2,202 | 25,580 |
| Western Terminus | | | | | |
| North Side | 4,816 | 577 | 2,197 | 0 | 7,590 |
| South Side | 1,836 | 4,870 | 17,414 | 495 | 24,615 |

## *Eelgrass Habitat*

Eelgrass is present in both study areas (eastern and western terminus) and extensive in some areas. The north side of the western terminus contains the least amount of eelgrass (7590 $m^2$) (Table 3). The underwater video camera assessment indicates that no observable eelgrass exists from the bridge north for approximately 175 m (Figure 2). In addition, no dense patches of eelgrass were noted. The southern side of the western terminus contained more eelgrass (24,615 $m^2$). Sparse and patchy areas were also located closer to the bridge structure (50 m) (Figure 3).

Isolated patches of eelgrass were located very close to the eastern terminus on both the north and south sides of the bridge, including a small area under the bridge (Figures 4 and 5). However, the coverage was generally discontinuous close to the bridge, and especially evident on the south side of the bridge (continuous cover at 80 m). On the north side, patch size and continuity increased closer to the bridge with dense cover beginning at approximately 75 m.

## *Substrate Type*

The dominant subtidal substrate recorded on the video was sand (Table 4). Some mixed coarse substrate and cobble were noted at the eastern terminus. Cobble was present at the deeper limits of the study area on the north side, and mixed coarse was present in the deeper portions on the southern side.

Certain substrate types were classified in the intertidal zone of the eastern terminus using CASI imagery. These included sand, gravel/cobble, and oysters/gravel, among other habitat classes (Table 5).

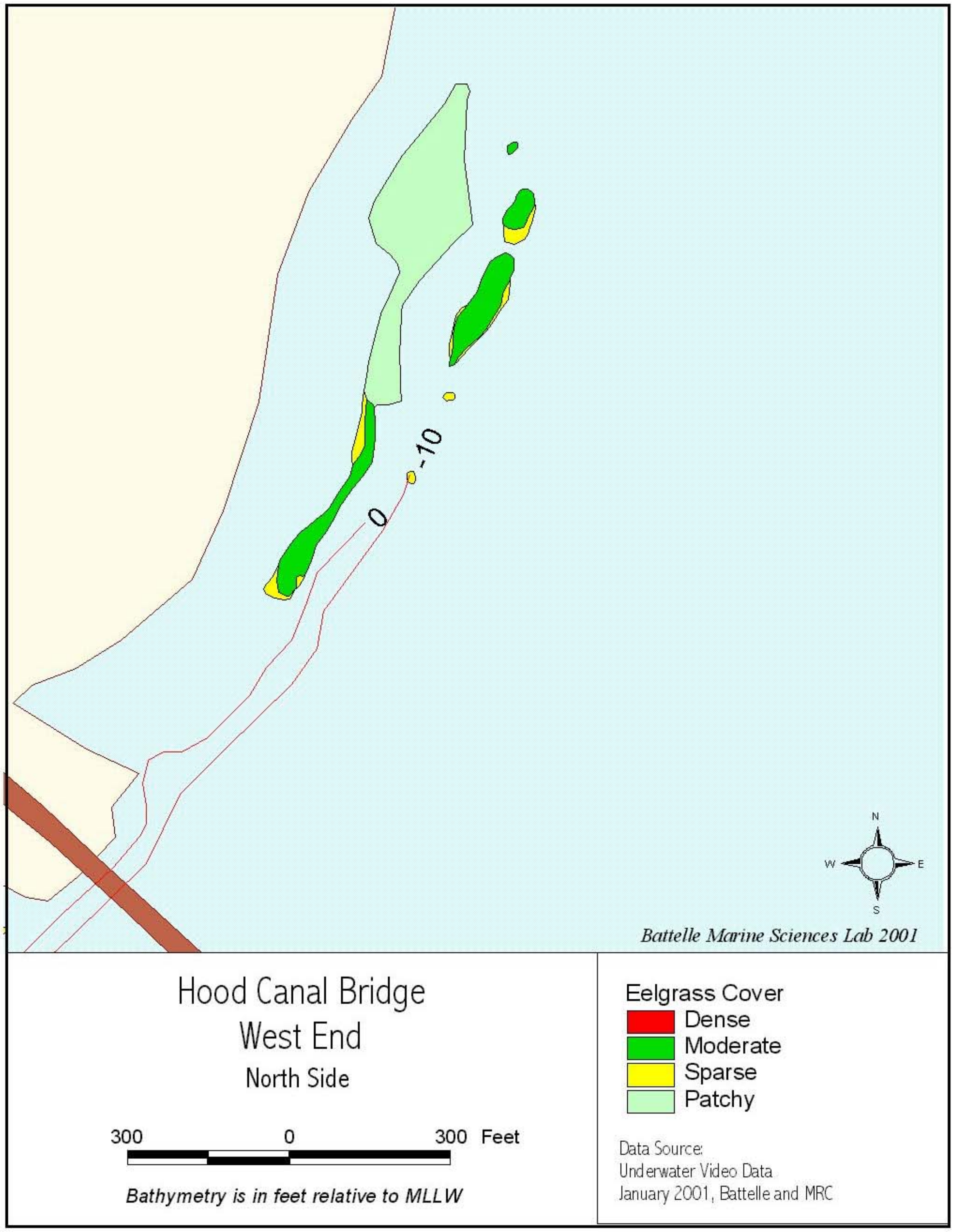


**Figure 2.** Eelgrass cover at the western terminus of the Hood Canal Bridge (north side).

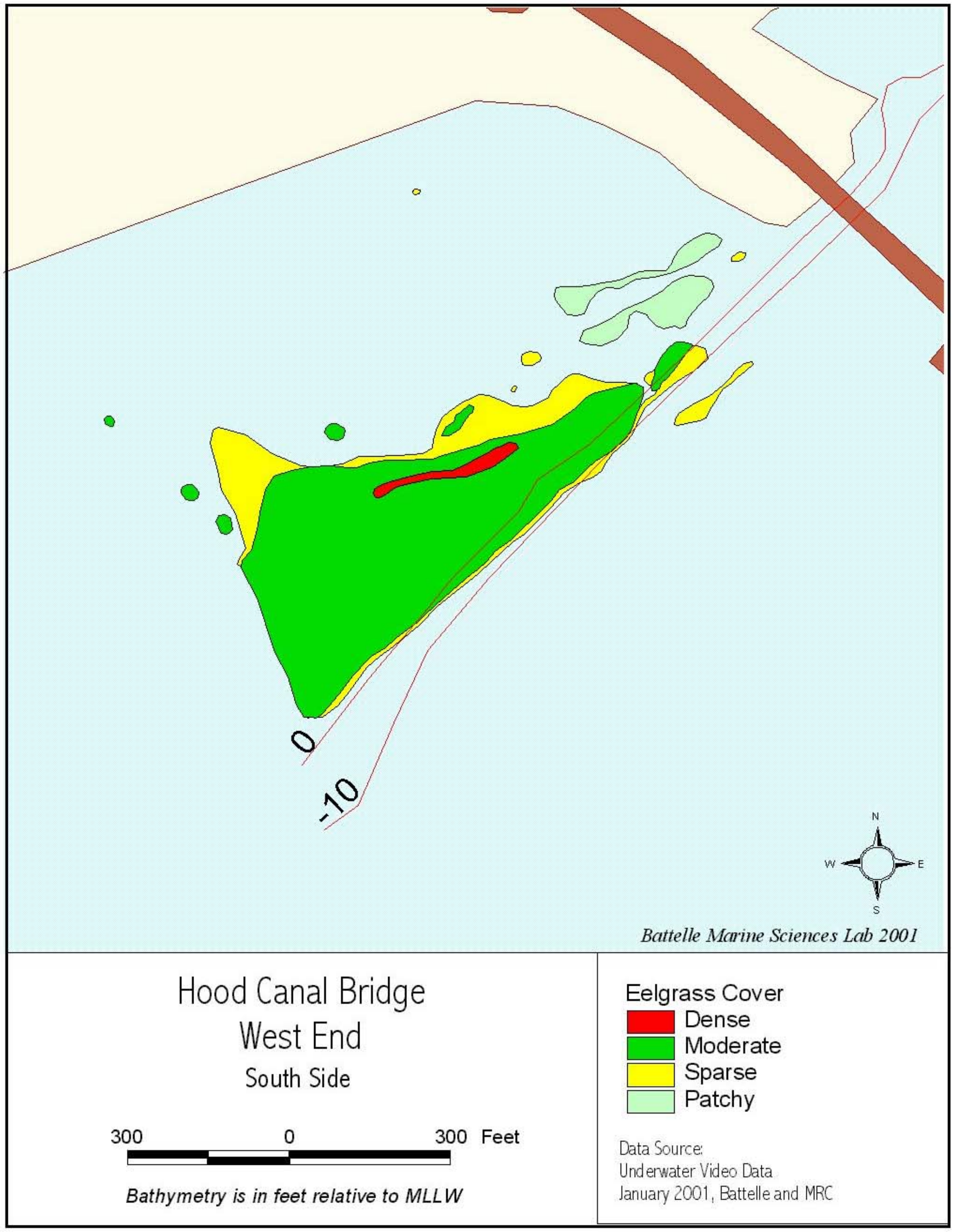


**Figure 3.** Eelgrass cover at the western terminus of the Hood Canal Bridge (south side).

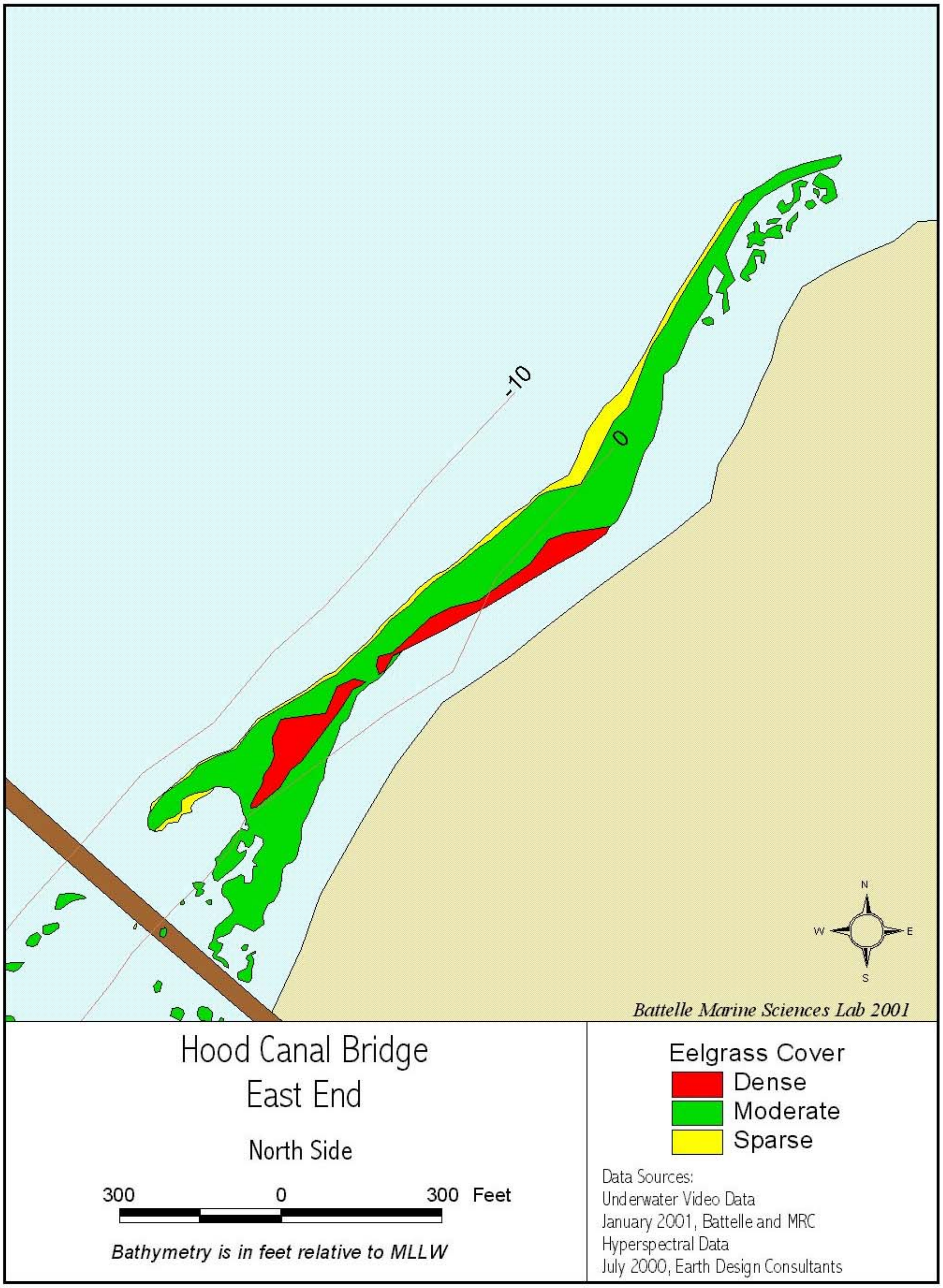


**Figure 4.** Eelgrass cover at the eastern terminus of the Hood Canal Bridge (north side).

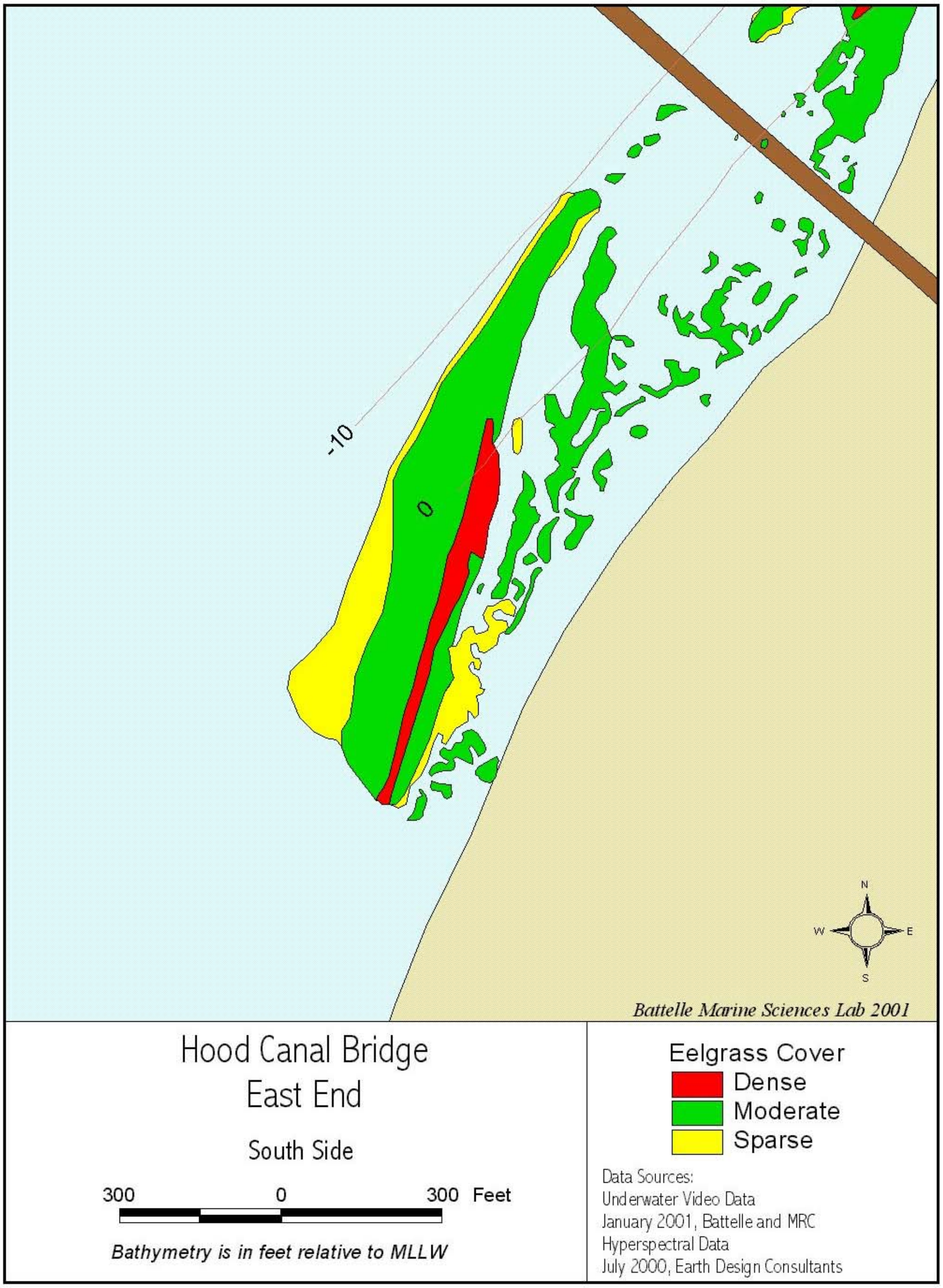


Figure 5. Eelgrass cover at the eastern terminus of the Hood Canal Bridge (south side).

**Table 4.** Number of Individual Subtidal Video Observations of Represented Substrate Types

| Substrate Type | Eastern Terminus | | Western Terminus | | Anchor Cable | |
|---|---|---|---|---|---|---|
| | North Side | South Side | North Side | South Side | North Side | South Side |
| Sand | 5,371 | 5,098 | 7,258 | 7,921 | 2,571 | 1,718 |
| Mixed Coarse | 318 | 1,698 | 405 | 84 | 368 | 78 |
| Cobble | 1,357 | 49 | 16 | 4 | 0 | 144 |
| Boulder | 0 | 4 | 33 | 29 | 0 | 0 |
| Total # Records | 7,129 | 6,849 | 7,712 | 8,038 | 2,939 | 1,940 |

**Table 5.** Basal Area Coverage ($m^2$) of Intertidal Habitats Classified Using CASI Imagery at Eastern Terminus of Hood Canal Bridge.

| Intertidal Habitats | North Side | South Side |
|---|---|---|
| Dense Eelgrass | 16,074 | 14,544 |
| Sparse Eelgrass | 1,118 | 857 |
| Green Algae | 724 | 1,828 |
| Sparse Green Algae | 2,970 | 3,699 |
| Brown Algae | 238 | 0 |
| Sand | 5,624 | 17,585 |
| Gravel/Cobble | 9,017 | 4,442 |
| Oysters/Gravel | 1,301 | 2,884 |
| Total | 37,066 | 45,839 |

## *Fish*

Several species of fish were present at the eastern and western terminus of the bridge, however, in low numbers (Table 6). The most common species were tubesnout (*Aulorhynchus flavidus*) and flatfish (Pleuronectidae). Ratfish (*Hydrolagus colliei*) were found frequently near the anchor cables and more commonly on the north side (Table 6).

## *Macroinvertebrates*

Benthic invertebrates commonly associated with rocky habitat (hard structures of the bridge and anchor cables) and open sand habitat were recorded on video in the study area (Table 7). A large aggregation of sand dollars (*Dendraster excentricus*) occurred on the south side of the western terminus close to shore. A smaller aggregation occurred on the south side of the eastern terminus, also close to shore. Crab, including Dungeness and Red Rock, were found frequently in the sand habitat. White-plumed anemones were found near the cable anchors and other hard structures associated with the bridge. Oysters were found at the south end of the eastern terminus close to shore. This was corroborated by the CASI imagery that recorded intertidal habitat. CASI also classified oysters in the northern portion of the eastern terminus in the intertidal zone.

**Table 6.** Number of Fish Observations from Subtidal Video Tracklines in Each Study Area.

| Fish Species | Eastern Terminus | | Western Terminus | | Anchor Cable | |
|---|---|---|---|---|---|---|
| [Line 1 – Individuals 1-10 fish]<br>[Line 2 – Schools (0-100 fish if applicable)] | North Side | South Side | North Side | South Side | North Side | South Side |
| *Aulorhynchus flavidus* (Tubesnout) | 0 | 0 | 2 | 2 | 0 | 0 |
| *Aulorhynchus flavidus* (Tubesnout) | 0 | 0 | 5 | 9 | 0 | 0 |
| *Citharicthys* spp. (Sanddab) | 0 | 1 | 0 | 0 | 1 | 0 |
| *Clypea harengus pallasi* or *Ammodytes hexapterus* (Herring or Sand Lance) | 0 | 0 | 0 | 1 | 0 | 0 |
| Cottidae (Sculpin) | 1 | 2 | 0 | | 1 | 1 |
| *Cymatogaster aggregata* (Shiner Surfperch) | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cymatogaster aggregata* (Shiner Surfperch) | 0 | 0 | | 4 | 0 | 0 |
| Embiotocidae | 0 | 0 | 0 | 0 | 1 | 0 |
| *Enophrys bison* or *Myoxocephalus lyacanhocephalus* (Buffalo or Great Sculpin | 0 | 0 | 0 | 1 | 0 | 0 |
| *Hexagrammos* spp. (Greenling) | 1 | 0 | 0 | 1 | 0 | 0 |
| *Hydrolagus colliei* (Rat Fish) | 0 | 0 | 1 | 1 | 61 | 20 |
| Liparididae (Snailfish) | 0 | 0 | 0 | 0 | 1 | 0 |
| *Ophiodon elongates* (Lingcod) | 0 | 1 | 0 | 0 | 0 | 0 |
| *Platichthys stellatus* (Starry Flounder) | 1 | 0 | 0 | 0 | 1 | 0 |
| Pleuronectidae (Right-eyed Flatfish) | 2 | 1 | 4 | 2 | 4 | 9 |
| Stichaeidae (Prickleback spp.) | | | 1 | | 0 | 0 |
| *Syngnathus* spp. (Pipefish) | 0 | 0 | 0 | 1 | 0 | 0 |
| Unidentified Fish | 2 | 0 | 1 | 3 | 12 | 6 |
| Unidentified Fish | 0 | 0 | 4 | 2 | 0 | 0 |
| Unidentified Flatfish | 2 | 6 | 5 | 1 | 21 | 17 |
| Unidentified Flatfish | 0 | 1 | 0 | 0 | 0 | 0 |
| Total | 9 | 12 | 23 | 28 | 103 | 53 |

**Table 7.** Number of Macroinvertebrate Observations from Subtidal Video Tracklines in Each Study Area.

| Invertebrate Species | | Density Code* | Eastern Terminus | | Western Terminus | | Anchor Cable | |
|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | | North Side | South Side | North Side | South Side | North Side | South Side |
| Anthozoa | Anemone | 1 | 65 | 27 | 9 | 2 | 98 | 59 |
| Asteroidea | Sea Star | 1 | 37 | 16 | 17 | 10 | 28 | 28 |
| *Balticina septentrionalis* | Sea Whip | 1 | 1 | 7 | 4 | 0 | 47 | 37 |
| *Cancer magister* | Dungeness Crab | 1 | 26 | 4 | 53 | 70 | 5 | 6 |
| *Cancer productus* | Red Rock Crab | 1 | 6 | 2 | 3 | 10 | 1 | 0 |
| *Cancer* spp. | Dungeness, Red Rock, or Slender Crab | 1 | 19 | 10 | 48 | 21 | 4 | 0 |
| *Crassostrea igas* | Pacific Oyster | 3 | 0 | 41 | 0 | 0 | 0 | 0 |
| Crustacea | Crab | 1 | 10 | 1 | 25 | 10 | 0 | 2 |
| *Dendraster excentricus* | Sand Dollar | 1 | 0 | 0 | 0 | 10 | 0 | 0 |
| *Dendraster excentricus* | Sand Dollar | 2 | 0 | 1 | 10 | 19 | 0 | 0 |
| *Dendraster excentricus* | Sand Dollar | 3 | 0 | 213 | 4 | 1,099 | 0 | 0 |
| Gorgonacea | Gorgonian Coral | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Henricia* spp. | Blood Star | 1 | 5 | 9 | 0 | 0 | 0 | 2 |
| *Metridium gigantium* | White-plumed Anemone | 1 | 1 | 3 | 64 | 14 | 182 | 19 |
| *Metridium gigantium* | White-plumed Anemone | 2 | 1 | 0 | 52 | 16 | 21 | 0 |
| *Metridium gigantium* | White-plumed Anemone | 3 | 0 | 0 | 0 | 0 | 12 | 0 |
| Pandalidae | Shrimp | 1 | 0 | 0 | 5 | 3 | 3 | 0 |
| Pandalidae | Shrimp | 2 | 0 | 0 | 0 | 33 | 0 | 0 |
| *Parastichopus californicus* | Sea Cucumber | 1 | 26 | 6 | 45 | 10 | 2 | 1 |
| *Pisaster* spp. | Short Spined, Giant Spined, and Ochre Sea Star | 1 | 102 | 58 | 11 | 6 | 7 | 2 |
| *Polinices lewisii* | Moon Snail | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Polychaeta | Polychaete Worm Tubes | 2 | 5 | 0 | 0 | 0 | 0 | 0 |
| *Ptilosarcus gurneyi* | Orange Sea Pen | 1 | 2 | 2 | 7 | 89 | 9 | 21 |
| *Pycnopodia helianthoides* | Sunflower Star | 1 | 86 | 75 | 186 | 76 | 36 | 16 |
| *Solaster* spp. | Stimpson's Sun Star, Dawson's Sun Star, and Northern Sun Star | 1 | 3 | 0 | 2 | 0 | 2 | 1 |
| *Urticina* spp. | Anemone | 1 | 38 | 57 | 8 | 2 | 40 | 51 |
| **Total # of observations** | | | 434 | 532 | 553 | 1,501 | 498 | 247 |

* Density Code: 1 = <5
2 = 5-10
3 = >10

## Conclusion

A primary interest of WSDOT as part of this mapping effort has been the proximity of eelgrass to the bridge structure at the eastern and western terminus. The underwater mapping effort was conducted during January 2001, during a season noted for dieback of eelgrass and senescence, whereas the CASI imagery was collected during the summer of 2000 when eelgrass cover was at a maximum. Although there were some minor differences in the eelgrass patch margins between the two methods, the vast majority of the areas overlapped along the eastern terminus where both methods were employed. Hence, the resulting maps for both the eastern and western terminus should be considered accurate delineations of eelgrass (cover type and geopositional accuracy). At both the eastern and western terminus, close to the bridge, a general lack of eelgrass continuity was noted. However, continuous beds were mapped on both sides at varying distances from the bridge. The merged intertidal-subtidal eelgrass maps are one of the first integrated mapping efforts of nearshore eelgrass in the Northwest. The spatially referenced data collected on substrate type, fish, and macroinvertebrates, will allow examination of habitat usage in the future near the eastern and western terminus of the bridge.

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# Appendix A

**Mapping Intertidal Eelgrass Habitat in the Vicinity of the Hood Canal Floating Bridge, Washington, using High Resolution Hyperspectral Imagery**

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# Mapping Intertidal Eelgrass Habitat in the Vicinity of the Hood Canal Floating Bridge, Washington, using High Resolution Hyperspectral Imagery

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October 2001

## Abstract

Intertidal and shallow subtidal eelgrass (*Zostera marina*) is an important natural resource of Puget Sound, and it distinguished as essential habitat for several species and life history stages of outmigrating juvenile Pacific salmon (*Oncorhynchus* spp.). Summer chum salmon (*Oncorhynchus keta*) may be particularly reliant on the integrity of eelgrass habitat in Hood Canal because of the migratory corridor and food resources eelgrass provides for these ESA-listed fish. However, until the recent advent of high-resolution remote sensing, it has been difficult to delineate and map eelgrass habitat such that habitat structure can be assessed at multiple scales. Only during the past few years has it become feasible to collect data at an appropriate spatial scale with enough information to separate similar habitat classes. With this newly acquired capability, it is now possible to evaluate the precise distribution and structure of eelgrass habitat relative to past and future shoreline modifications, in order to better mitigate impacts to important resources such as Pacific salmon. Here we describe mapping of the intertidal eelgrass habitat landscape in the vicinity of the Hood Canal Floating Bridge, Hood Canal, Washington. The general purpose of this project was to delineate eelgrass distribution and habitat structure with sufficient precision that it could be precisely linked to subtidal mapping of eelgrass using different technology, thus providing a comprehensive intertidal-subtidal characterization of the eelgrass habitat. We used the Compact Airborne Spectrographic Imager (CASI) to collect 19-band imagery along two flightlines of Hood Canal shoreline ~1 km north and south of the eastern terminus of the Hood Canal Floating Bridge. During the period of image acquisition, field teams systematically collected training site data on intertidal habitat composition (i.e., plant and substrate cover) and measured

reflectance spectra on the ground using a hand-held radiometer. We used GPS to obtain precise location of a combination of field installed control points and image-to-image (DOQ) to geocorrect flightlines. In the two flightlines used to map the eelgrass habitat landscape around the eastern terminus of the Hood Canal Floating Bridge, CASI imagery had an RMSE of between 2.1 m and 4.6 m. We used ERDAS Imagine® to perform a combination of unsupervised and supervised classification that, in combination with the field-collected training data permitted discrimination of eelgrass from macroalgae and dense from sparse eelgrass. Although other habitat cover, such as different substrates, was not a key element of the training site data collection, we were also able to distinguish unvegetated sediment structure to some accuracy. The resulting supervised classification habitat map illustrates both contiguous and fragmented eelgrass in the vicinity of the Hood Canal Floating Bridge. Accuracy of dense and sparse eelgrass, assessed by comparison of overlap with eelgrass delineated by Battelle Pacific Northwest National Laboratories, Marine Science Laboratory using underwater videography, was 95% and 86%, respectively.

## Introduction

The Washington State Department of Transportation (WSDOT) is planning to replace portions of the existing Hood Canal Floating Bridge, particularly the eastern terminus. The associated construction activities are expected to involve replacement of the eastern half of the floating structure, placement of 20 new anchors with associated benching and filling, foundation drilling, addition of concrete footings and girders, bridge widening, demolition of existing structures, and construction activities from anchored barges. Many of these and related construction activities on both sides of the bridge have the potential for significant impacts on local marine resources, including shading from barges, noise and vibration from heavy equipment use, and bottom disturbance from anchors and material placement. A critical step of the assessment of this impact is a spatially specific evaluation of potentially vulnerable resources in the vicinity of the bridge and associated construction sites, including biological resources such as geoduck clams (*Panope abrupta*) and rockfish (*Sebastes* spp.) and habitats such as eelgrass (*Zostera marina*) that is an important landscape feature for key species such as migrating juvenile Pacific salmon (*Oncorhynchus* spp.). Battelle Pacific Northwest Laboratory's (PNNL) Marine Science Laboratory (MSL) is assessing the benthic resources and intertidal/subtidal habitats associated with the bridge site.

We used the opportunity of an on-going evaluation of estuarine/nearshore marine habitat status of juvenile summer chum salmon in Hood Canal, Washington (Simenstad 2000), that also involved systematic data collection on shoreline modifications and geomorphic characteristics, to provide high-resolution assessment of the intertidal eelgrass habitat in the study area. The larger project, coordinated by the Point-No-Point Treaty Council (PNPTC), is investigating the cumulative impact of eelgrass habitat landscape modifications over all Hood Canal and eastern Strait of Juan de Fuca subestuaries and shorelines (Simenstad *et al.* 1999).

# Methods

Our approach was to utilize digital imagery from an airborne hyperspectral sensor that would: (1) provide us with appropriate and sufficient spectral resolution to confidently distinguish eelgrass from other intertidal vegetation; (2) acquire data of sufficient spatial resolution (e.g., <2 m) to delineate eelgrass habitat structure appropriate to the scale of response of important resources, such as migrating juvenile salmon; and (3) achieve georeferencing precision on relatively the same scale as the image resolution and training site data collection.

## Spectral Image Acquisition

We employed a CASI sensor, developed by Itres Research, Ltd., and operated by Hyperspectral Data International, Inc. (HDI; see *http://www.hdi.ns.ca*) to use digital radiometric information from two flightlines along the eastern shoreline of northern Hood Canal (Fig. 1) on 2 July 2000 (18:83-18:43 UTC). CASI is a two-dimensional CCD array-based pushbroom imaging spectrograph, and is equipped with a downwelling incident light sensor. We mounted the CASI sensor in a DeHavilland Beaver[1] equipped with a factory-installed camera port. The aircraft collected digital hyperspectral data on 2 July 2000 by following the shoreline at an altitude of 1143 m AGL at approximately 176-183 km $hr^{-1}$. At an average of 1.5-m spatial resolution, the flight track swath was 768 m (512 pixels) wide. The CASI sensor, operated in the spatial mode, was adjusted to record reflected light from 19 non-overlapping channels (Appendix 1). A ~2 km shoreline segment (Fig. 1) associated with the eastern terminus of the Hood Canal Floating Bridge was clipped from the 13-km combination of flightlines #26 and #28.

## Training Site Data Collection

*Habitat Structure*

To associate reflectance spectra of intertidal habitat types with the CASI imagery, we ground surveyed the cover of vegetation and substrate at eight precisely located training sites between 29 June and 2 July 2000 (Table 1). We selected representative intertidal habitat types at each training site from large, relatively monotypic patches representing varying eelgrass and other coverage. At the time of sampling, training sites were assigned one of ten cover classes. Percent cover was estimated visually from five randomly-selected 2.25-$m^2$ (1.5-m x 1.5-m) quadrats from within a 6-m x 6-m (16 cell) sampling grid. GPS data were collected for the corners of each grid such that the training site data could be reliably located on the geocorrected CASI imagery. Down looking, digital camera images were also obtained by ground teams for each sampling grid cell at the same time as the visual estimations.

After completion of CASI image acquisition and field data collections, the digital photographs were organized by training site. Digital photographs of each grid cell at each habitat and training site were analyzed for percent cover using a point quadrat method, where a 100-point grid is superimposed on the digital image and the sum

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[1] The aircraft was provided by Ecotrust, one of the other partners and subcontractors in the larger PNPTC research.

intersection with intertidal plants or substrates determines the overall cover composition. Based on the digital images from all habitat sampling grids, twenty cover classes (including various combinations of plants and substrates) were defined. Given the lack of sufficient training site data to discriminate many of these cover types, we aggregated them into eight cover classes represented within the study region (see Classification, below).

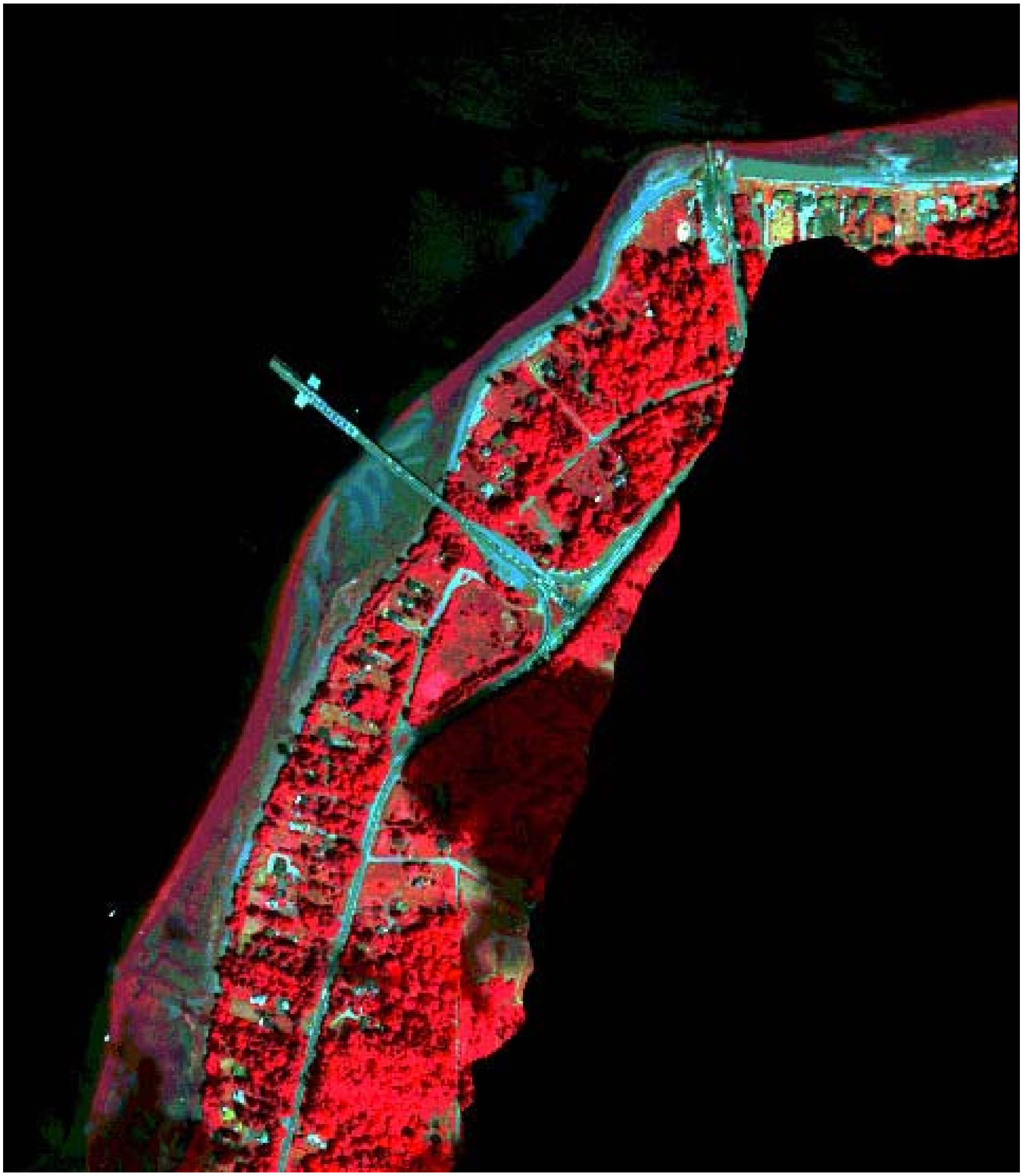

Figure 1 Flightline of CASI hyperspectral image acquisition at the eastern terminus of the Hood Canal Floating Bridge, northern Hood Canal, Puget Sound, Washington, on 2 July 2000.

*Habitat Spectral Reflectance*

We used a Photo Research, Inc.® PR-650 hand-held radiometer to record reflectance spectra, at 8 nm interval from 380 to 780 nm, from monotypic habitat strata (vegetation, substrate) along the Hood Canal shoreline at the same time of airborne image acquisition. Five replicate measurements were made for each habitat strata under the ambient light conditions. A spectral library, used to select CASI band combinations for supervised classification, was constructed from these data.

Table 1 Location and habitat types constituting training site data used to classify CASI hyperspectral data from the intertidal habitat in the vicinity of the eastern terminus of the Hood Canal Floating Bridge, Hood Canal, Washington. Note: training data from 147 sites located throughout Hood Canal were used for this classification including those for Sparse Green Algae, which were not found in the area of this study.

| Training Site | Dense Eelgrass | Sparse Eelgrass | Green Algae | Sparse Green Algae | Brown Algae | Sand | Gravel/ Cobble | Oyster/ Gravel |
|---|---|---|---|---|---|---|---|---|
| **HNT-4: Lofall** | X | X | X | | | X | | |
| **HNT-8: Kings Spit** | X | X | | | | | | |
| **HCT-1: Scenic Beach** | | X | X | | X | X | | |
| **HCT-2: S. Hoods Head** | X | | | | | X | | X |
| **HCT-7: X Aycock Pt.** | | | X | | X | | | X |
| **HCT-8: Dewatto** | X | | | | X | | X | |
| **HNT-6: Green Point** | X | | X | | | | | |
| **HNT-7: S. Browns Pt.** | X | | X | | | | X | |

## Image Processing

Initially CASI data were radiometrically corrected by HDI and supplied in ERDAS LAN format. Reflectance values were calculated using irradiance recorded by the incident light sensor, and original radiance values recorded by the CASI, resulting in a processed data file in which variation due to downwelling irradiance has been removed. These data were geocorrected using filtered attitude data. CASI imagery was classified (see below) and imported into ESRI ArcView® software for incorporation into a Geographic Information System (GIS) dataset.

## Geoposition Correction

We established a series of ground control points (GCP) for this study. We installed 3X3 m plastic sheets, which were visible in the CASI imagery, along the shoreline. We also located conspicuous features (i.e., road crossings, building corners, piers, etc.) from digital orthoquads (DOQs). In all cases, we established precise geographic control points using a Trimble® Pathfinder real-time differential Global Positioning System (GPS) at the pre-installed white targets or locations identifiable from the imagery. ERDAS® Imagine was used to geometrically correct the CASI imagery by fitting the imagery to the control points using a 1st order polynomial model. Approximately 20 GCPs were used for each flightline. Using this approach, root mean square error (RMSE) is measured as the spatial error associated with the GCPs following geometric correction. In the two flightlines used to map the eelgrass habitat landscape around the eastern terminus of the Hood Canal Floating Bridge, the CASI imagery had an RMSE of 2.1 m for flightline #26 and 4.6 m for flightline #28, significant improvements on the DOQ accuracy of 4.5 m and 5.8 m respectively. Further geographic control points were obtained during the accuracy assessment field visit in May 2001 (see below).

## *Classification of Eelgrass Habitat*

We used a combination of unsupervised-supervised classification. Initially, we performed an unsupervised classification (ISODATA, 12 iterations, 95% convergence, 100 classes) on the 19 band, georeferenced imagery using ERDAS® Imagine® software, which resulted in 100 spectral categories. Following the collection of signatures in ISODATA, the 100 spectral classes were subjected to a Maximum likelihood classification. For supervised classification, we extracted spectral signatures from our training sites. Signature locations were measured directly from the targets for placement on the imagery in order to avoid any error associated with the geocorrection process. In most cases, training sites were situated between 10-50 m of GCP tarps; therefore, we were relatively certain of their position relative to the visible marker in the imagery.

During pilot studies in 1999, we found that we could only use 4 or 5 CASI bands in a supervised classification due to the relatively small size of our training plots. To speed up processing and address limitations in the classification procedure, we selected 4 bands (CASI Bands 2, 8, 16, and 18) for supervised classification based, in part, on measurements with the hand-held radiometer. We produced a new set of spectral signatures for eelgrass and other habitat types. Maximum Likelihood was used with the resulting signatures to group pixels that shared spectral characteristics. The eelgrass habitat landscape was delineated in raster form for eight aggregated cover classes: (1) dense eelgrass, (2) sparse eelgrass, (3) green algae, (4) sparse green algae, (5) brown algae, (6) sand, (7) gravel/cobble, and (8) oysters/ gravel.

The accuracy of the supervised classification was tested in the field during the 22-23 May 2001 field trip (see below). Based on those results, we adjusted the oyster and sand spectral ranges to better capture the actual cover classes. In the case of wet sand, which had a spectral signature significantly overlapping that of oysters, we used a wetness mask to extract the wet sand. This mask was produced by using the highest bands in the infrared range and interactively determining a threshold point between the wet and dry sand. The polygons determined to be wet sand were then merged with the previously mapped dry sand.

### *Accuracy Assessment*

On May 22-23, 2001, with the assistance of PNPTC representatives, we visited the study site to assess initial habitat classifications and to further interpret intertidal habitat cover that was poorly represented in our July 2000 dataset. Single point, line and polygon GIS data around discrete habitat covers were collected with the Trimble® Pathfinder real-time differential GPS. Digital photographs were taken in multiple directions from the center of large patches of monotypic habitats (e.g., habitat classes that we wished to delineate in the supervised classification of the CASI imagery) and the GPS position (based on a Magellan Map410 hand-held GPS) of the photopoint was recorded. Although almost 11 months had passed since the early July 2000 CASI data acquisition, we assumed that the unvegetated habitat cover classes (e.g., large gravel, etc.) had not changed significantly a year later. We also assumed that the eelgrass had not changed significantly at the center of its distribution, but acknowledge that the eelgrass edge may have changed significantly during that period.

To further evaluate the spatial accuracy of our CASI hyperspectral delineation of eelgrass in the lower tidal elevations, we also compared our data to the separate subtidal-lower intertidal eelgrass map generated by PNNL-MSL using underwater digital videography during the winter of 2001. In the PNNL-MSL study, geo-positioned observations were manually coded to an ARCView shape file from underwater video. This study was designed to map the extent of subtidal and lower intertidal eelgrass bed distribution and recognized three categories of eelgrass density: sparse (0-10% cover), moderate (10-50% cover), and dense (>50% cover). Eelgrass bed edges were also mapped. Although we cannot use these data to assess the accuracy of all CASI-derived habitat classes, comparison between this independently derived data set and classification of CASI flightlines does provide some indication of how well CASI captured eelgrass presence. We converted the PNNL-MSL data to a 1.5-meter pixel file that matched the CASI data and extracted all non-zero cells. This resulted in a spatial data set yielding 1,947 PNNL-MSL observations that overlapped eelgrass mapped with our CASI data.

## Results

Eelgrass coverage is extensive in the study area but shows obvious discontinuity in the vicinity of the eastern terminus of the Hood Canal Floating Bridge, where much of the intertidal is unvegetated (by either eelgrass or macroalgae) (Fig. 2). In accordance with the limiting factors on *Zostera marina* distribution (e.g., Phillips 1984; Fonsecca et al. 1998), under optimal conditions (substrate, elevation, wave and current exposure) dense eelgrass typically forms a contiguous band in the lower tidal elevations. The supervised classification of the CASI imagery indicates that this continuity is maintained throughout the ~2 km shoreline in the study area except for approximately 73 m to the south and 104 m to the north of the Bridge terminus. Eelgrass coverage becomes somewhat more patchy and sparser at higher tidal elevations at several other locations, typically at projecting points in the shoreline, but dense eelgrass coverage is still contiguous at the lower elevations. Based on FRAGSTATS® statistics (McGarigal and Marks 1995) of the supervised classification GIS (shape) characterization of the study site, the 327 patches of eelgrass together compose 9.72 ha, or almost exactly 50% of the intertidal habitat captured by the CASI imagery. Sparse eelgrass (369 patches) covers 0.31 ha, or

1.6% of the intertidal area. The other dominant habitat classes in the study area included sand (3.12 ha; 16.0%), gravel/cobble (2.61 ha; 13.4%), sparse green algae (predominantly *Ulva* sp. and *Enteromorpha* spp.; 1.78 ha; 9.2%) and oysters (*Crassostrea gigas*; 1.08 ha; 5.6%).

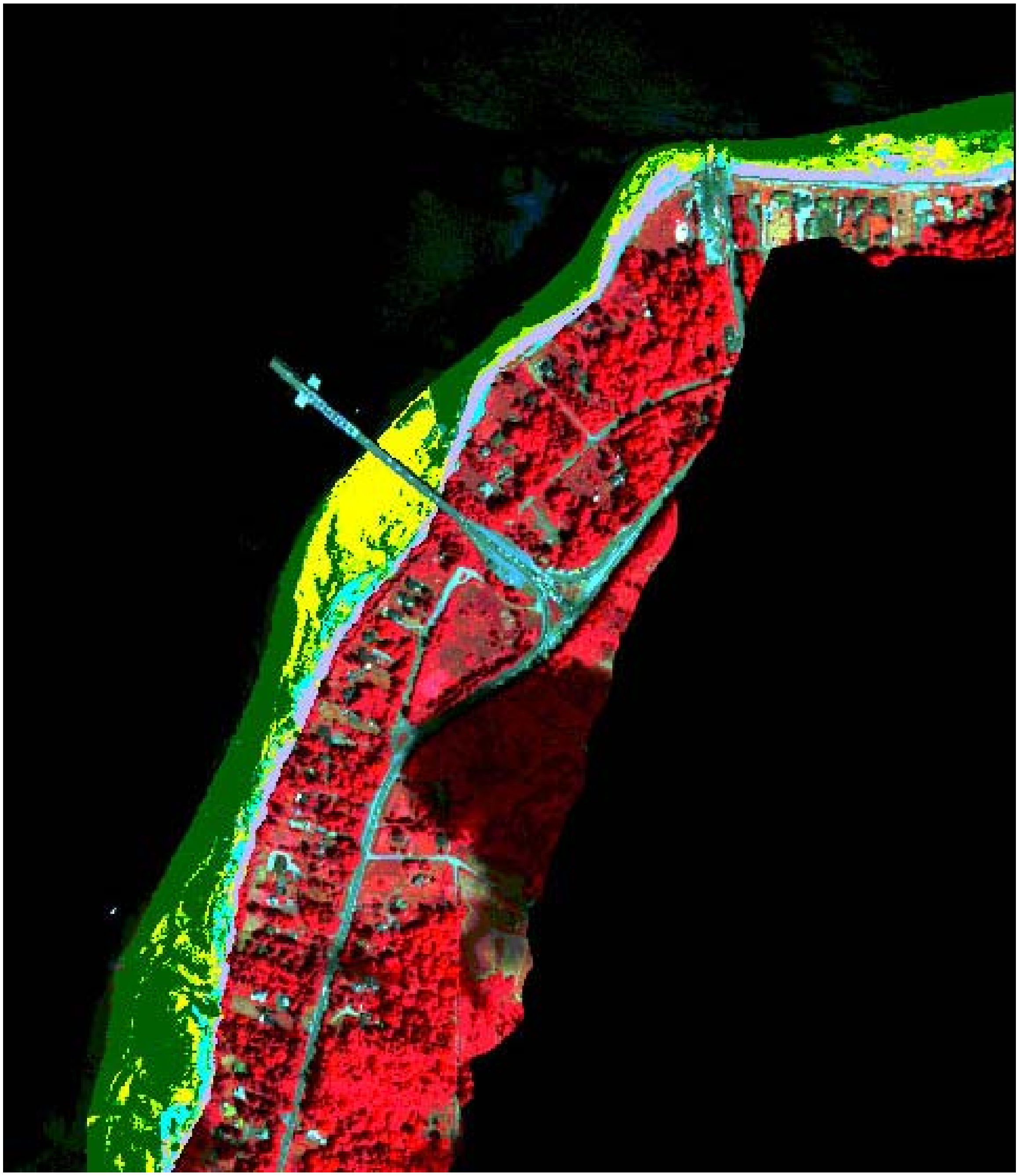

Figure 2 Results of supervised classification of hyperspectral image acquisition at the eastern terminus of the Hood Canal Floating Bridge, northern Hood Canal, Puget Sound, Washington, on 2 July 2000. Dark green indicates dense eelgrass, while other shades of green and brown are sparse eelgrass and several cover classes of algae; unvegetated substrates (sand, gravel, oysters) are shades of yellow, gray and light blue. The intertidal landcover

has been overlaid on the original CASI image (bands 16,9,3), in which red is terrestrial vegetation and roads and houses are aqua and green.

In evaluating geoposition accuracy of eelgrass through the comparison of the CASI to the PNNL-MSL videography data, we determined that both dense and sparse eelgrass delineated by the two independent remote sensing techniques intersected to a surprising degree, especially considering seasonal differences (Table 2). Although the eelgrass density categories do not match exactly, 95% of the areas classified as dense eelgrass in the CASI imagery were recorded as moderate to dense eelgrass in the PNNL-MSL dataset. Also, 86.4% of CASI pixels classified as sparse eelgrass were recorded as sparse to moderate eelgrass in the PNNL-MSL dataset. However, about 18% of all the points classified as non-eelgrass areas in the CASI imagery (green algae, etc.,) were recorded as eelgrass in the PNNL-MSL dataset. Finally, we acknowledge that there is some spatial error associated with both datasets.

Table 2 Correspondence of observations made from underwater video interpretation and classified CASI hyperspectral imagery.

| | **CASI Classes** | | |
|---|---|---|---|
| | **Dense Eelgrass** | **Sparse Eelgrass** | **Other** |
| **WADOT Classes** | | | |
| **0 - 10% (sparse)** | 73 | 7 | 109 |
| **10 - 50% (moderate)** | 1036 | 63 | 207 |
| **> 50% (dense)** | 405 | 11 | 36 |

## Discussion

Based on the high spectral and spatial resolution CASI hyperspectral image analysis from 2000, eelgrass intertidal habitat landscape structure in the vicinity of the eastern terminus of the Hood Canal Floating Bridge has been accurately delineated to a high degree of cover and geoposition accuracy. Assuming common geocoordinate systems, the eelgrass habitat structure that we have delineated in the intertidal should overlay precisely with that generated by PNNL-MSL mapping of the subtidal and lower intertidal habitat using videography. While there may be some differences in eelgrass patch margin between our July 2000 sampling by CASI and the winter 2001 videography sampling (e.g., maximum patch growth in summer; senescence and decrease in eelgrass cover in winter), it is likely that at least the core areas of the eelgrass patches should overlap. This intertidal-subtidal mosaic of eelgrass habitat will to our knowledge be the first integrated mapping of nearshore eelgrass in this region.

This study was not designed to determine the potential causes of the intertidal habitat structure in the study area. Accordingly, we cannot speculate whether the distinct lack of eelgrass proximal to the Bridge is a consequence of the Bridge construction or structure or a normal phenomenon. Our continuing assessment of eelgrass habitat structure in Hood Canal and the eastern Strait of Juan de Fuca will hopefully provide more substantive correlative information on the natural variability in eelgrass habitat structure as well as the incidence and characteristics of any eelgrass habitat discontinuity around shoreline structures. It is notable, however, that the shoreline geomorphology and orientation (e.g., to wind/wave action) is not significantly different from other slight points along the nearshore to the south, where eelgrass patch structure remains contiguous.

## Acknowledgments

This research was supported by the Washington Department of Transportation through a subcontract with Battelle Pacific Northwest National Laboratories, Marine Science Laboratory. We gratefully acknowledge the support of Dana Woodruff and Ron Thom in facilitating this research. Chris Weller, Ted Labbe and Alan Mortimer of the PNPTC provided assistance above and beyond the original support of the PNPTC hyperspectral survey. Herb Ripley, of HDI, and ECOSTUST were also valuable partners in achieving the CASI image acquisition. An incredible cadre of individuals, too many to name but all greatly appreciated, contributed immensely to the intensive vegetation training site data gathering and geocontrol point collection.

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# Appendices

## *Appendix A: CASI Channel Settings for CASI sensor during July 2000 data acquisition, Hood Canal, Washington.*

| ***Channel*** | **Wavelength (nm)** |
|---|---|
| 1 | 830-860 |
| 2 | 860-890 |
| 3 | 800-820 |
| 4 | 775-785 |
| 5 | 730-740 |
| 6 | 765-775 |
| 7 | 785-795 |
| 8 | 540-550 |
| 9 | 720-730 |
| 10 | 700-710 |
| 11 | 755-765 |
| 12 | 550-560 |
| 13 | 690-700 |
| 14 | 520-530 |
| 15 | 530-540 |
| 16 | 560-570 |
| 17 | 640-650 |
| 18 | 460-490 |
| 19 | 630-640 |
| 20 | 620-630 (not used 2000, 2001) |
| 21 | 650-660 (not used 2000, 2001) |

## *Appendix B: Metadata*

| | | | |
|---|---|---|---|
| **1. IDENTIFICATION INFORMATION** | | | |
| **A. Data layer Name** | veg_brdg | | |
| B. Data layer Description | Landcover – east end of Hood Canal Bridge, WA | | |
| C. Coordinates | | | |
| Xmin/Ymin | 529803.181 | 5299102.5 | |
| Xmax/Ymax | 528415.681 | 5300643.0 | |
| D. Layer Production Environment | | | |
| **Computer Hardware** | PC | | |
| Operating System | Windows NT and Windows 98 | | |
| Software Used | ERDAS Imagine version 8.4 | | |
| ***E. Data Source*** | | | |
| Spatial Resolution (meters) | 1.5 | Row Count | 1028 |
| Minimal Mapping Unit | 1.5 meters | ***Column Count*** | 926 |
| Data type | Arc Info GRID | | |
| File Size | 76.2 kb | | |
| **2. SPATIAL REFERENCE INFORMATION** | | | |
| A. Map Projection | UTM | | |
| B. Spheroid | WGS84 | | |
| C. Datum | WGS84 | | |
| D. Units | Meters | | |
| E. Parameters | | | |
| | | | |
| **3. ATTRIBUTE INFORMATION** | | | |
| Intertidal landcover types – 8 classes: (1) dense eelgrass; (2) sparse eelgrass; (3) green algae; (4) sparse green algae; (5) brown algae; (6) sand; (7) Gravel/ Cobble; and (8) Oyster / Gravel. | | | |
| | | | |

| | |
|---|---|
| **4. DATA QUALITY INFORMATION** | |
| A. Accuracy Assessed? | Limited: Spatial Error +/- 2.1 to 4.6 m. Classification accuracy, unknown. |
| **5. LINEAGE** | |
| A. Data Source | Compact Airborne Spectrographic Imager (CASI) 19-band imagery acquired 2 July 2000 from aircraft flown at 1,143 m AGL at 176-183 km $hr^{-1}$. |
| B. Date of Update | August 15, 2001 |
| C. Explanation | Imagery collected as part of a larger study by Point No Point Treaty Council, 7999 NW Salish Lane, Kingston, WA 98346. |
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